Three-dimensional Dam Break

1 Introduction

This case provides a description for three-dimensional dam break use case in which a volume of fluid formulation is used in the presence of air and water mixing.

2 Domain

The three-dimensional geometry for this tutorial is captured in Figure 1. A tank of dimension 3.22 x 1 x 1 m in the streamwise (x-), vertical (y-), and spanwise direction (z-direction), respectively, includes a rectangular obstruction (0.161 meter in height, 0.403 m in width, and 0.16 m in length) 0.6635 m from the end of the domain. An initial block of water 0.55 m in height and 1.228 m in length (spanning the full width of the tank) is released, [1].

The top boundary is an open boundary in which a static pressure is supplied. All other boundary surfaces are specified to be a no-slip wall boundary condition.

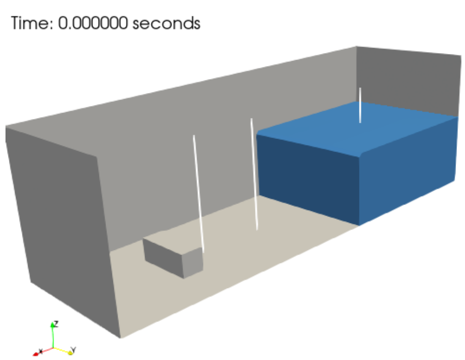

Figure 1: Three-dimensional dam break geometry. Also shown are the experimental height probes that are ordered from the obstruction backward, H1, H2, and H3.

3 Theory

The air/water configuration is represented by the following set of transport equations,

Continuity:

$$\frac{\partial u_j}{\partial x_j} = 0. \tag{1}$$

Momentum:

$$\frac{\partial \rho u_i}{\partial t} + \frac{\partial \rho u_j u_i}{\partial x_j} - \frac{\partial \sigma_{ij}}{\partial x_j} = F_i. \tag{2}$$

Volume of Fluid:

$$\frac{\partial \alpha}{\partial t} + u_j \frac{\partial \alpha}{\partial x_j} = 0. \tag{3}$$

In the above equation, ρ is the fluid density, α is the volume of fluid, and u_j is the fluid velocity. The stress tensor is provided by

$$\sigma_{ij} = 2\mu S^*_{ij} - P\delta_{ij}, \tag{4}$$

where the traceless rate-of-strain tensor is defined as

$$S^*_{ij} = S_{ij} - \frac{1}{3}\delta_{ij} S_{kk} = S_{ij} - \frac{1}{3}\frac{\partial u_k}{\partial x_k}\delta_{ij}.$$

The momentum equation includes the general source term F_i, which contains both gravitational, ρg_i, and surface tension effects, $\sigma\kappa\frac{\partial \alpha}{\partial x_i}$. Here, σ is the surface tension of the liquid and κ is the curvature, $\kappa = -\frac{\partial n_j}{\partial x_j}$, with the surface normal, n_j, defined as,

$$n_j = \frac{\frac{\partial \alpha}{\partial x_j}}{\|\frac{\partial \alpha}{\partial x_j}\|}, \tag{5}$$

In a low-Mach flow, the above pressure, P, is the perturbation about the thermodynamic pressure, P^{th}. Surface tension can also be applied in this configuration.

Properties as a function of the volume of fluid via a linear relationship,

$$\phi = \phi^L \alpha^L + \phi^G (1 - \alpha), \tag{6}$$

where ϕ^L and ϕ^G are the properties at a pure liquid and gas state, respectively. Therefore, α is interpreted at the volume fraction of liquid, where a value of unity implies pure liquid. The isosurface of 1/2 represents the diffuse interface between liquid and air.

The underlying methodology exercises a balanced-force method for pressure stabilization in the presence of multi-phase flow, see Francois *et al.* [2] and the more recent unstructured control-volume finite element method work of Domino and Horne [3].

4 Results

We follow the numerical validation approach of Kleefsman *et al.* [1] where prediction of water level heights at various stations and time are provided. These data files are available in the postP directory.

4.1 Simulation Specification and Results

The density of air and water are specified to be 1 and 1000 kg/m^3, respectively, while the viscosity for air and water are 1.98e-5 and 1.0e-3 $Pa - s$, respectively. The coarse mesh simulation exercises a Hex8 linear element.

In Figure 2, results are provided for the specifications provided above.

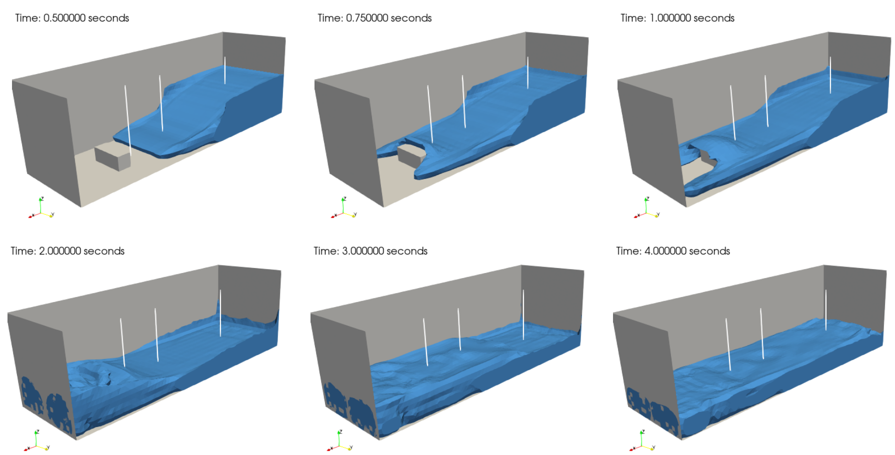

Figure 2: Volume of fluid evolution at 0.5, 0.75, 1.0, 2.0, 3.0, and 4.0 seconds.

5 Discussion Points

There are several interesting activities associated with this sample case including the following:

- Explore the mesh and input file specifications associated with this case.
- Replicate Figure 2 using Paraview. Here, load the data set and perform a "clip" based on the scalar value of volume of fluid to be one-half.
- Probe all degree-of-freedom results, i.e., velocity and pressure. What is of interest?
- Set the line command "activate_buoyancy_pressure_stabilization: no", and add an additional source term to the momentum system by the name *buoyancy*. Re-run and report and differences.

References

[1] Kleefsman, K., Fekken, G., Veldman, A., Iwanowski, B., and Buchner, B., *A balanced-force algorithm for continuous and sharp interfacial surface tension models within a volume tracking framework*, Journal of Computational Physics, Vol. 1, pp.141-173, 2006.

[2] Francois, M. M., Cummins, S. J., Dendy, E. D., Kothe, D. B., Sicilian, J. M., Williams, M. W., *A Volume-of-Fluid based simulation method for wave impact problems*, Journal of Computational Physics, Vol. 1, pp.363-393, 2005.

[3] Domino, S. P., Horne, W., *Development and deployment of a credible unstructured, six-DOF, implicit low-Mach overset high-fidelity simulation tool for wave energy applications*, Renewable Energy, under review, 2022.